ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 26 (2011) 1626 – 1632

Procedia Engineering

www.elsevier.com/locate/procedia

First International Symposium on Mine Safety Science and Engineering

Heat Transfer Analysis on Double-skin Air Tube in Ventilation of Deep Mine Heading Face

Zhang Shuiping*, Qin Juan, Chen Gang

Faculty of Resourse and Environmental Engineering. Jiangxi University of Science and Technology ,ganzhou, 34100,China

Abstract

For the high temperature at heading face in deep mines, double-skin air tube was analyzed based on the theory of heat transfer and hydrodynamics, and it is recommended that the condition of air layer between two tubes is an important factor in thermal insulation. According to the ventilation of heading face in deep mine, the distribution of velocity and the temperature of the air within tube were simulated by using ANSYS software, and the thermal insulation effect was discussed. The result indicates that double-skin air tube has good effect on thermal insulation, and the number of air intakes and the thickness of the air layer are two important factors to the thermal insulation effect. The thermal insulation effect drops by increasing the number of air intakes. When the air layer thickness is less than 20mm, the outlet temperature decreases significantly. Conversely, the temperature decreases unnoticeably.

Selection and/or peer-review under responsibility of China Academy of Safety Science and Technology, China University of Mining and Technology(Beijing), McGill University and University of Wollongong.

Keywords: Deep mine heat harm; Double-skin air tube; Air thermal insulation; Numerical simulation; Air layer thickness

0 Introduction

Through the survey of the main deep hot mine we can find[1]: if ventilation in good condition, most of the airflow temperature can meet the requirements of safe production because they are relatively low in the throughout roadway. High temperature points of mine are focus on heading face, and most of these

* Tel.: 86-797-8312529;
E-mail: zhsp@mail.jxust.cn

1877-7058 © 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.proeng.2011.11.2347

working faces have poor ventilation, so the deeper mine working face, the closer the air temperature of work environment to the temperature of the original rock.

Aim to the high temperature phenomena of the heading face , the cooling method of non-ice air conditioner were usually used， for example, matching the local ventilation of the mini-high pressure blower and the PVC ventilation tubing which has rigid and light weight material[1], double ventilation tubing ventilation and cooling technology and so on[2]. Because there is a big difference in temperature between airflow from internal ventilation tubing and airflow form internal roadway, heating transfer will happen between the ektexine of ventilation tubing and the internal wall of ventilation tubing which will reduce ventilation cooling effect. Air has the advantage of small heat conductivity coefficient and light weight, and the method of air thermal insulation layer is currently applied in many fields [3-5], so the method of using the double-skin air tube were proposed to improve the ventilation effect, and the effect of air thermal insulation and impact factors were analysed through heat transfer theory and numerical simulation analysis to determine the air layer thickness.

1 Analysis of thermal insulation theory of double-skin air tube

1.1 The structure of the double-skin air tube

Double-skin air tube is comprised of ordinary air tubes of different diameters which filled the air layer. If the air layer thickness too large, it will cause heat convection to weaken the effect of air thermal insulation. Structural diagram of double-skin air tube as is shown in Fig. 1.There are some air inlet in one end of the ventilation tubing of internal wall, when the draught fan opened, some airflow entered the mid air layer from the pores. If the air flow to stabilize, the middle layer of air will be at rest, because internal and external layers air tube were separated by air.

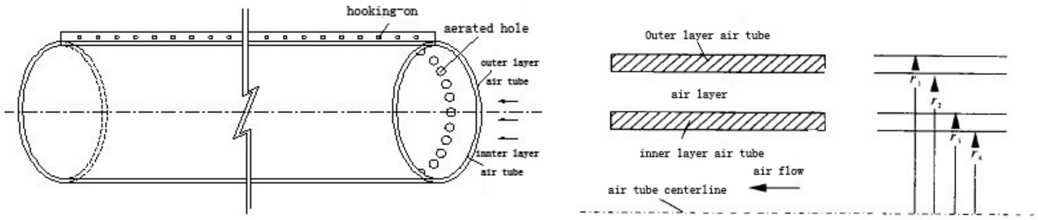

Fig. 1 Structural diagram of double-skin air tube

1.2 Heat insulation study

For the double-skin air with the length L, we assume the heat conductivity coefficient of the air tube and air layer are λ and λ_{air} respectively, the heat conductivity coefficient inside and outside air tube compound surface are hi and h0， the fluid temperature inside and outside of the air tube are t_i and t_0, and its diameter is d_i(i=1,2,3,4). The outer air tube was supported by static pressure. Thermal transmission between air tube inside and outside can be regarded a process as follows: heat through the outer, air layer, the inner, and to reach the airflow steady state in air tube orderly. If supposing the heat transfer rate Φ_{double} in each level was of the same, and Φ_{double} could be expressed as [6]:

$$\Phi_{double} = \frac{\pi L(t_0 - t_i)}{\frac{1}{h_i d_4} + \frac{1}{2\lambda}\ln\frac{d_3}{d_4} + \frac{1}{2\lambda_{air}}\ln\frac{d_2}{d_3} + \frac{1}{2\lambda}\ln\frac{d_1}{d_2} + \frac{1}{h_0 d_1}} \quad (1)$$

If the ordinary single-skin air tube length is L (external diameter and inside diameter were expressed as d_2 and d_1), and to express heat transfer rate with Φ.

$$\Phi = \frac{\pi L(t_0 - t_i)}{\frac{1}{h_0 d_1} + + \frac{1}{2\lambda}\ln\frac{d_1}{d_2} + \frac{1}{h_i d_2}} \quad (2)$$

By the above two formulas we can conclude that if double-skin air tube and single-skin air tube have the same length, and also have the same $\Delta T = t_0 - t_i$, the heat transfer rate Φ which flow through the single-skin air tube is much more than the heat transfer rate Φ_{double} which flow through the double-skin air tube. Therefore, we could get the smaller airflow temperature rise to reach the heading face by using of double-skin air tube and improve the working face of high temperatures situation more effectively.

1.3 Determination of the air layer thickness

Compared with the air layer, the inner and outer air tube thermal resistance is quite small; the key factor of thermal insulation in double-skin air tube is controlled by the state of the air layer. According to the heat transfer theory of air-interlayer structure [6], in a certain temperature difference, the middle state of the air will depend on grashof number (Gr_δ) whose characteristic length is the air layer thickness δ.

$$Gr_\delta = \frac{g\alpha\Delta t\delta^3}{\nu^2} \quad (3)$$

Where, g——acceleration of gravity
α——coefficient of cubical expansion
Δt——temperature difference between airflow and air tube wall
ν——kinematic coefficient of viscosity of fluid

When the Gr_δ is low, heat change is totally dependent on heat conducting, as Gr_δ rise, there will be an obvious convection phenomenon, to enhance heat change. According to air-interlayer experiments correlation [6,7], if air-interlayer is horizontal and $Gr_\delta \le 2430$, the heat transfer in air-interlayer is pure; When $Gr_\delta \ge 10000$, the cross-ventilation phenomenon is obvious. Airflow is a variable, but the best range of air layer thickness can be determined. According to the simulation, if the temperature of air tube wall (maximum temperature of airflow) is 32℃, and temperature of airflow in air tube entrance (minimum temperature of airflow) is 25℃,using formula 3, we will get $\delta \le 14$mm, if $Gr_\delta \le 2430$;we can get $\delta \ge 22.4$mm, if $Gr_\delta \ge 10000$. Therefore, the air layer thickness is 14~22.4mm in the condition of no manifest cross-ventilation phenomenon.

2 Numerical simulation analysis

2.1 Establishment of model

In order to study the influence factor and the effect of heat insulation of double-skin air tube, and compared it with single-skin air tube, we chose air tube length and diameter were 120m and 0.4m respectively after taking into account the actual situation of double-skin air tube in ventilation of deep mine heading face, the inlet of air flow is the outlet of draught fan, and the outlet of airflow is the outlet of air tube, and regard air tube as cylinder, half cylinder of the cutting plane is the simuland, computing domain and mesh generation as shown in Fig. 2.

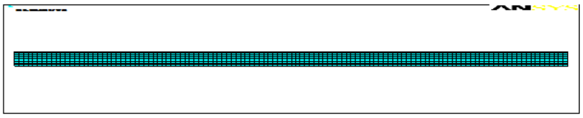

Fig. 2 computing domain and mesh generation

2.2 Analog computation process

Simplified model of the computational domain are followed: 1) airflow is the stationary flow in air tube.2) Compared with the air layer, the thermoresistance of air tube small enough to be negligible. 3) Air leakage can be ignored where in the process of local ventilation. Airflow is the average of inlet and outlet airflow, and airflow at outlet is homogeneous distribution. 4) Air tube centerline is coincides with laneway centerline. Air flow density change is so slightly that can be considered as incompressible fluid. For steady state flow of planar and incompressible fluid, governing equation can be expressed as follows[8]:

$$\left.\begin{aligned} \frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}&=0 \\ \rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)&=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \\ \rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)&=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \\ u\frac{\partial t}{\partial x}+v\frac{\partial t}{\partial y}&=a\left(\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}\right) \end{aligned}\right\} \quad (4)$$

Where, u、v——fluid velocity respectively in the x, y direction component.

ρ——fluid density

p——fluid pressure

μ——coefficient of kinematic viscosity of fluid

a——thermal diffusivity of heat conductor

Boundary conditions: 1) Keep steady temperature T=298K in model inlet, even pace V=20m/s, put pressure in model outlet P=0; 2) The wall have no slip boundary, the components of the wall speed is 0 m/s. 3) Keep steady temperature T=305K in wall model. 4) Radial velocity V=0m/s is imposed on air flow centerline. Apply module FLOTRAN in ANSYS software, and use Standard onflow standard model to simulate the air-flow field and temperature field in the air tube.

2.3 Analysis of result

2.3.1 Interpretation of the result of velocity field simulation

In the process of flow field simulation, if we impose different speed at the air tube inlet, the distribution of air flow velocity within the air tube is similar. When the wind speed is 20m/s, the wind speed distribution along the direction of flow were shown in Fig. 3.

Considering the air flow and the practical situation, the simulation of the entire double-skin air tube is divided into 12 sections, each tube has the length of 10m, and suction ports were designed in air flow inlet of each tube. Fig. 4 shows the on-way distribution of wind speed. The Figure shows, air flow in suction port of air layer has the most dramatic changes in the radial velocity, and circumfluence occurs, it have significant impact on mainstream in air tube. Wind speed distribution is periodic, the period is the distance between every two inlets， and other locations within the air layer approach to stationary.

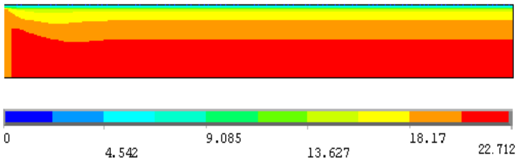

Fig. 3 Air flow velocity within the single-skin air tube

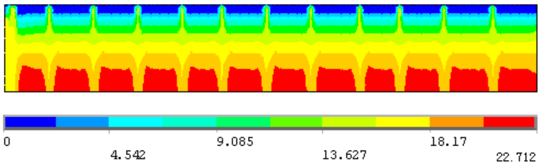

Fig. 4 Air flow velocity within the double-skin air tube

2.3.2 Interpretation of result of temperature field simulation

Fig. 5 shows the airflow temperature distribution along the single-skin air tube, and Fig. 6 is a curved shape which shows the temperature changes along the centerline, and the airflow temperature between outlet and wall are similar, it shows that the single-skin air tube has poor thermal insulation. Temperature changes along the single-skin air tube can be divided into 3 parts: part 1 is airflow entrance which has small temperature gradient of airflow, because tube wall have resistance, and make the temperature rise slowly in the center line; Airflow temperature increased rapidly in the part 2, because airflow and wall have big temperature difference and great performance of heat transfer; the temperature rise become slower in the part 3, because the airflow temperature is increased after absorb heat, and temperature difference between tube and wall become small and reduce heat transfer.

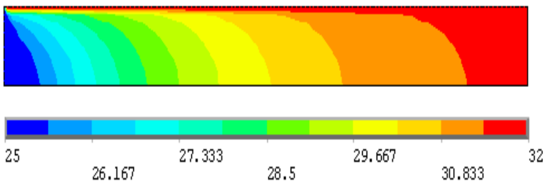

Fig. 5 the airflow temperature distribution along in the single-skin air tube

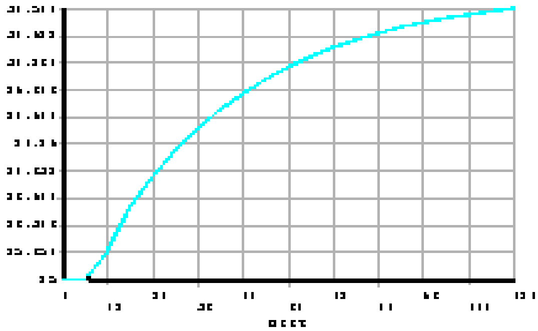

Fig. 6 a curved shape shows the temperature changes along the single-skin air tube centerline

In order to analyze the influence of pore on mainstream temperature, there are two cases of double-skin air tube temperature field simulation: 1) Only one inlet position was set in the air-layer, Fig. 7 shows the distribution of the airflow temperature along the double-skin air tube. 2) We can get the thermal insulation tubes are 120 meters long by connecting the thermal insulation tubes with the section length of 10 meters. Fig. 8 shows the airflow temperature distribution in the double-skin air tube. From the Fig. 8, we can get that if set air inlet louvers, they will reduce heat-insulating property, and add the temperature gradient, and finally it lead to greater air tube outlet temperature.

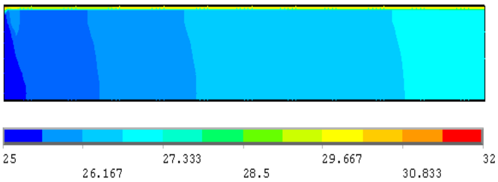

Fig. 7 the first picture of airflow temperature distribution in the double-skin air tube

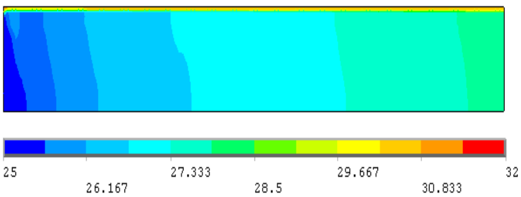

Fig. 8 the second picture of airflow temperature distribution in the double-skin air tube

In order to analyze the impact of tube outlet temperature on air layer thickness, we calculate the air layer thickness which is 14~22.4mm according to grashof criteria and simulate near this value. From the Fig. 9, if the air layer thickness δ<20mm, with the δ increasing, the airflow outlet temperature were reduced significantly; if δ>20mm, with increasing δ , the temperature don't change obviously, and ultimately determine the best air layer thickness is 20mm.

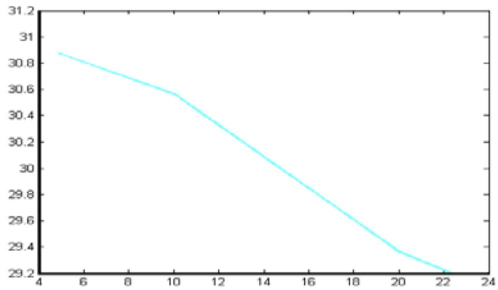

Fig. 9 relation curve of tube outlet temperature and δ

3 Conclusions

(1) According to heat transfer theory and hydrodynamics theory, the paper analysed the mechanism of heat insulation and the factors that affect the thermal barrier effect. When the difference in temperature is the same between inlet and outlet, heat flow through the double-skin air tube is much smaller than ordinary single-skin air tube through the heat flow, the main factors affect the thermal barrier effect is the state of the air layer between the air tubes.

(2) Through the Simulation of airflow velocity pattern in air tube, we can get: Impose different velocity in single-skin air tube inlet, air flow velocity distribution are similar, there is obvious velocity boundary layer effect near the wall. The air inlet louvers of air layer in the double-skin air tube, air flow has the most dramatic changes in the radial velocity, and circumfluence occurs, it have significant impact on mainstream in air tube. Wind speed distribution is periodic, the period is the distance between every two inlets, and other locations within the air layer approach to stationary,

(3) Through the simulation of airflow temperature pattern in air tube, we can get: double-skin air tube has a good thermal barrier effect, the main factors affect the thermal barrier effect are the number of air inlet between air tubes and the air layer thickness. The number of air inlet increase，the thermal barrier effect drop off; If the air layer thickness δ<20mm, with the δ increasing, the airflow outlet temperature were reduced significantly; if δ>20mm, with increasing δ the temperature don't change obviously, and ultimately determine the best air layer thickness is 20mm.

References

[1] Li Zijun, Wu Chao, Zhou Bo. A New Ventilation and Temperature Drop Method for Dead Working Face and Its Effect Analysis[J] (in Chinese).Metal Mine,2002(1):51~53.

[2] Wu Qiang,Qin Yueping, Yao Minghua,Zhang Jinfeng. Study on measure of cooling air in driving road with two air pipes[J]. Journal of China Coal Society,2002,27(5):499~502.

[3] Na Wei, Zou Pinghua Thermal analysis of vacuum layer in steel jacketed vacuum insulated directly buried steam pipelines[J]. 2006, 36(2):1~5.

[4] Meng Fankang,Ying Zhixiang,Yan Minghui. Double deck glass airspace thickness variation on experimental study of thermal resistance effects[J]. Energy Conservation, 2007(6):54~57.

[5] Zhao Li. Thermal insulation calculation and analysis of air layer of double roofing airspace[D]. Zhejiang University, 2008

[6] Yao Zhongpeng,Wang Ruijun. Pm Louis Peng[M].Beijing Institute of Technology Press,2003

[7] Holman J P. Heat transfer. 8th ed. New York: McGraw-Hill Companies, 1997.

[8] Tao Wenquan. Numerical heat transfer[M].Xi'an Jiaotong University Press, 2001